Viability of high intensity interval training in persons with spinal cord injury—A perspective review

Running title: interval training in spinal cord injury

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Abstract

Spinal cord injury (SCI) leads to loss of sensory and motor function below the level of injury leading to paralysis and limitations to locomotion. Therefore, persons with SCI face various challenges in engaging in regular physical activity which leads to a reduction in physical fitness, increases in body fat mass, and reduced physical and mental health status. Moderate intensity continuous training (MICT) is recommended to enhance physical fitness and overall health status in this population, but it is not always effective in promoting these benefits. High intensity interval training (HIIT) has been promoted as an alternative to MICT in individuals with SCI due to its documented efficacy in healthy able-bodied individuals as well as those with chronic disease. However, the body of knowledge concerning its application in this population is limited and mostly composed of studies with small and homogeneous samples. The aim of this review was to summarize the existing literature regarding the efficacy of HIIT on changes in health- and fitness-related outcomes in this population, denote potential adverse responses to HIIT, describe how participants perceive this modality of exercise training, and identify the overall feasibility of interval training in persons with SCI.

Introduction

In the last decade, incidence of spinal cord injury (SCI) in the United States has increased from about 12,000 new cases in 2010 to 17,500 in 2017 [1]. This trend is concerning considering the dramatic decline in physical and psychological function occurring soon after SCI as well as the huge economic costs of this injury, which can be more than $1,000,000 in the first 12 months post-injury [1]. Occurrence of SCI typically reduces participation in physical activity, leading to a decline in multiple indices of physical fitness and onset of skeletal muscle atrophy, body fat accretion, and adverse lipid profiles and insulin resistance that are detrimental to cardiometabolic health. It is evident that individuals with SCI are more deconditioned than other disability groups [2], which in turn markedly enhances their risk of heart disease and diabetes versus able-bodied populations (AB) [3]. This elevated risk warrants identification and implementation of practical, accessible, and effective programs of physical activity to reverse the decline in health status characteristic of SCI.

Physical Activity Guidelines for persons with SCI [4] recommend 20 min/d of moderate-to-vigorous intensity continuous training on a minimum of 2 d/wk combined with 2 d/wk of resistance training as a minimum threshold for achieving fitness benefits. It is noteworthy that these guidelines have less volume than recommended for AB adults [5] (150 min/wk of MICT and 2 – 3 d/wk of resistance training) despite the substantially lower fitness level and small exercising muscle mass characteristic of people with SCI. A recent study [6] in individuals with chronic SCI demonstrated significant increases in VO_2max and muscular strength versus controls after a 16 wk exercise regimen following the guidelines, yet outcomes including fasting insulin and blood lipids, vascular health, and body composition were unchanged with training [7]. These results suggest that this guideline has insufficient volume or intensity of exercise to modify various risk factors for cardiovascular disease in persons with SCI. Indeed, the most recent evidence-based physical activity guidelines for adults with SCI [4] suggest that 3 d/wk of moderate-to-vigorous intensity aerobic training is necessary for improvements in cardiometabolic risk factors. However, these recommendations are still based on a relatively small number of predominantly under-powered studies, with little attempt to identify different training modes to achieve the moderate-vigorous intensity goals denoted in the recommendations.

In the last two decades, there has been tremendous interest in the utility and efficacy of high intensity interval training (HIIT) in healthy AB individuals [8] as well as those with diabetes [9] or heart disease [10]. High intensity interval training differs from MICT as bouts are discontinuous, consisting of repeated 1 – 4 min bouts at workloads equal to 85 – 95 %HRmax separated by recovery ranging from 1 – 3 min [9]. In a systematic review of 28 studies containing 723 participants, Milanovic et al. [11] demonstrated small but superior increases in VO_2max in response to chronic HIIT compared to MICT in AB adults. Based on a review of 65 studies, Batacan et al. [12] reported significant increases in outcomes related to cardiometabolic health in overweight and obese AB individuals. Across studies, training volume is not typically considered, although frequently volume is significantly lower with HIIT compared to MICT. A more intense modality of HIIT referred to as sprint interval training (SIT), constituting repeated efforts at intensities above that associated with VO_2max or peak power output (PPO), has also been shown to elicit similar outcomes in AB as MICT [13] while being more time efficient, as the actual exercise volume per session ranges from 40 s to 3 min in duration. Together, these data support the efficacy of interval training in various groups of healthy AB adults as well as those at risk for chronic disease.

As a recent review [14] established the rationale for employing HIIT in persons with SCI, we believe it is unnecessary to further emphasize the potential for this type of exercise training in this population. Consequently, the focus of this review is to summarize the available evidence concerning the efficacy of interval training on changes in VO_2max, exercise tolerance, and health-related markers in wheelchair-dependent persons with SCI by examining results from various training studies. In addition, a secondary aim is to establish the tolerability of HIIT by summarizing how persons with SCI perceive this mode of training, which sheds light on the 'real-world' application of interval training in this population.

What is the cardiometabolic stress of interval training in persons with SCI?

Examining efficacy of interval training in a person with SCI requires that these bouts actually elicit intensities characteristic of near-maximal exercise. Consequently, it is merited to describe various physiological responses to this modality, as the acute physiological response to HIIT and SIT obtained in AB adults performing lower-body exercise cannot automatically be applied to individuals with SCI, based on marked differences in autonomic function and size of muscle mass activated which is dependent on exercise mode (arm ergometry versus cycle ergometry or treadmill). Data from eight men and one woman with SCI (age = 33 ± 10 yr, 2 with tetraplegia and 7 with paraplegia) revealed that HIIT (eight 60 s bouts at 70 %PPO) and SIT (eight 30 s "all-out" efforts at 105 %PPO) performed on an arm ergometer elicit relative intensities equal to 90 %HRmax [15], which is similar to values obtained in active AB participants [16]. More recent data from this laboratory [17] reveal that slightly different bouts of acute HIIT and SIT elicit approximately 87 – 88 %HRmax. Results from these studies also demonstrated significantly higher blood lactate concentration (BLa) in response to HIIT and SIT (4 – 8 mmol/L) versus MICT, reflecting enhanced contribution of glycolysis to ATP supply. Unfortunately, many studies employing interval-based exercise in persons with SCI did not report the HR response to training. For example, Harnish et al. [18] denoted that “the subject achieved a HR near age-predicted maximum HR on several occasions.” In other studies [19,20], the authors only reported absolute HR values in response to training rather than as a %HRmax.

Overall, these data show that when persons with SCI perform acute bouts of upper-body dependent HIIT or SIT at near-maximal to supramaximal effort, they likely do elicit relative intensities characteristic of high intensity interval training observed in AB adults performing large muscle mass exercise such as running or cycling. Nevertheless, we encourage scientists to report the relative HR response to acute sessions of interval training as a %HRmax to confirm that participants are truly engaging in this modality of exercise. If these values are impractical to use, as in the case of persons with tetraplegia who have a blunted response to exercise, we recommend that Rating of Perceived Exertion be used to set intensity, and that participants be exercising at power outputs eliciting values above 5 on the Borg [21] 1 - 10 scale, or 15 on the 6 – 20 scale [22] representing “hard.” This recommendation is based on prior data showing that RPE is suitable to prescribe interval exercise in AB adults [23] and vigorous exercise in persons with SCI [24].

Does high intensity interval training actually work in persons with SCI?

Table 1 summarizes data from eight studies including 43 men and women who performed chronic interval training exercise for 4 – 12 weeks. These studies were accessed from the Authors’ personal collections as well as through a literature search on PubMed using the terms ‘high intensity interval training’ and ‘spinal cord injury.’ Results were obtained from case studies [18], single group designs [25-27], and randomized controlled trials comparing effects of interval training to MICT. Participants included those with acute and chronic SCI who were classified with paraplegia or tetraplegia. These data show significant increases in VO_2max, insulin sensitivity, and PPO in response to various interval training regimes. Hasnan et al. [25] and Brurok et al. [26] reported a 20 to 24 % increase in VO_2max in response to hybrid-based HIIT, similar to that reported by Tordi et al. [27] (19 %) in response to 4 wk of wheelchair ergometry. However, these improvements are lower than the 52 % increase in VO_2max demonstrated in a case study [18] that is superior to recent results [19] showing an 8 % increase in VO_2max in response to 6 wk of SIT, or an 18 % increase in response to 16 wk of MICT [6]. In response to home-based wheelchair interval training, Gauthier et al. [28] demonstrated no change in VO_2max, which suggests that this regimen was inadequate to elicit increases in cardiorespiratory fitness. Overall, it seems that HIIT or SIT significantly increase VO_2max and PPO in persons with SCI, although it is unclear if these adaptations are superior to those accrued with high-volume MICT as seen in AB adults [11]. Nevertheless, there are currently no standardized guidelines for prescribing HIIT or SIT in persons with SCI, so it is difficult to compare results obtained from studies that use entirely different protocols for implementing HIIT or SIT.

How is high intensity interval training perceived in persons with SCI?

Adoption and widespread use of a new exercise paradigm such as HIIT or SIT require that the training is well-tolerated and that the patient will be willing to perform it, irrespective of the potential health and fitness-related benefits that it may elicit. One barrier to regular physical activity in AB adults is a lack of enjoyment [29], and Hagberg et al. [30] exhibited that enjoyment measured with a visual analogue scale was positively related to exercise frequency in primary care patients. Findings from a recent systematic review in AB adults revealed that acute bouts of HIIT elicit favorable perceptual responses including enjoyment and affective valence that are not different than those obtained from bouts of MICT [31]. Unfortunately, there is a paucity of data concerning enjoyment responses to interval training in persons with SCI. One study in nine habitually active men and women with chronic SCI reported higher post-exercise enjoyment in response to acute sessions of HIIT and SIT versus MICT despite the higher HR and BLa response inherent with interval training [15]. A more recent study [20] in persons with acute SCI showed high enjoyment scores (106 out of 126) in response to SIT that were similar to those seen with MICT (20). These results can be explained by the intermittent pattern of interval training as well as the degree of accomplishment characteristic of these bouts that is not experienced during MICT until the end of the session [32].

Another outcome related to adherence to physical activity is the level of pleasure:displeasure experienced during exercise, which is widely assessed using the Feeling Scale [33], a validated measure of affective valence. This survey is an 11-point scale with anchors of "very good" (+5), neutral (0), and "very bad" (-5). When MICT is performed below the lactate threshold, affective valence is typically positive, yet as intensity surpasses this threshold, affective valence declines due to onset of interoceptive cues related to hyperventilation and blood lactate accumulation (BLa) [34]. As interval training is at near-maximal work rates, it would be expected to elicit an aversive response. Data from AB adults showed that affective valence measured during a brief session of aerobic exercise was predictive of exercise behavior 6 and 12 mo later [35] which emphasizes the importance of this measure in promoting long-term exercise adherence. To our knowledge, only one study has examined changes in this outcome during interval exercise in persons with SCI, and results showed similar affective valence (~3, "good") between HIIT, SIT, and MICT despite the higher BLa attendant with acute bouts of interval exercise [15]. More studies are needed to better understand perceptual responses to interval training due to their association with adherence to physical activity.

Feasibility and accessibility of high intensity interval training in persons with SCI

The majority of studies employing HIIT or SIT were performed in a laboratory or rehabilitation center with expensive equipment (arm ergometer, metabolic cart, etc.) and trained personnel overseeing exercise [15,18-20,26]. In these facilities, intensity can be prescribed based on indices including %HRmax or %PPO obtained from a baseline graded exercise test to exhaustion. Relative exercise intensity can also be carefully monitored and adjusted by trained professional staff, where the participant only has to be concerned with performing the bout. However, this paradigm may not translate well outside of a clinic to the "real-world" where individuals with SCI are responsible for performing physical activity on their own. In this setting, we recommend that intensity be prescribed based on RPE as denoted above, in which the exerciser should attain a value representing "hard." Prior data in inactive AB adults [36] showed that home-based HIIT consisting of various body weight exercises performed "all-out" led to significant increases in VO_2max. In active persons with chronic SCI, Gauthier et al. [28] examined the feasibility and efficacy of home-based HIIT performed using their own wheelchair via completing repeated 30 s bouts at RPE between 6 – 8 ("very hard"). Although neither VO_2max nor muscular strength were improved in response to this 6 wk intervention, participants did not report any serious adverse events, deemed training to be feasible, and reported significant subjective improvements in health. However, training was not supervised, intensities were not matched, and participants completed amounts of habitual activity during this regimen, which likely led to dissimilar training loads amongst participants. In sedentary AB men and women, Reljic et al. [37] reported significant increases in VO_2max and reductions in total low-density lipoprotein in response to an 8 wk regimen of HIIT performed in group fitness classes. This finding reveals the promise of employing group-based HIIT in persons with SCI, although this is likely only practical in specialized rehabilitation centers or adapted fitness facilities with specialist supervision.

Whether high intensity interval training is actually feasible or acceptable in persons with SCI has been examined in two recent studies. Astorino and Thum [15] reported that all participants preferred HIIT or SIT versus an acute session of MICT, although these individuals were all habitually active. When participants with chronic SCI were asked to perform self-managed interval training in their wheelchair, they reported that the regimen was satisfactory, feasible, and that they intended to continue this training in the future [28]. In this study, adherence to training was 86 %, which is similar to another study from this group performed in persons undergoing acute rehabilitation (86 %) [20], yet slightly lower than that reported in other studies (92 %, [38]; 100 %, [19]. Although preliminary, these data suggest that persons with SCI find HIIT or SIT to be tolerable and that they can comply to the rigors of this training modality. The implementation of SIT is extremely attractive considering its similar efficacy compared to MICT in persons with SCI [19,20] and minimal time commitment, as lack of time has been cited as a barrier to physical activity in persons with SCI [39]. In addition, the rapid gains in exercise tolerance and cardiorespiratory fitness demonstrated in response to SIT may lower the economic cost of exercise training when employed in inpatient or outpatient rehabilitation by reducing the number of visits (and time) needed to improve function. Future interval training studies are necessary to determine whether such exercise protocols improve exercise adherence and to confirm whether the associated adaptations lead to sustained improvements in biomarkers of cardiometabolic disease.

Does completion of high intensity interval training elicit any side effects or adverse responses?

As previously stated, no exercise-based intervention will be widely instituted in patient populations if it causes severe side effects or adverse responses. Because of the limited data concerning HIIT in persons with SCI, it is relatively premature to conclude that it is safe to implement in all individuals with SCI. Even if it were, questions remain concerning how long following an SCI it would be safe to start implementing such vigorous exercise, particularly given the demands on the core stabilizing muscles around the trunk and spine. However, existing data do not reveal severe side effects from participating in HIIT or SIT. McLeod et al. [20] reported no change in pain in response to 6 wk of SIT in persons with sub-acute SCI, and only one incidence of post-exercise hypotension which occurred during the first of 15 sessions. Two of six patients with SCI undergoing hybrid interval training reported shoulder dysfunction, yet this was diminished with rest and therapy [26]. Similarly, shoulder pain was also reported by participants performing wheelchair interval training [28]. It is possible that the low volume nature of interval training, especially characteristic of SIT, may be useful in alleviating onset of shoulder discomfort. Astorino and Thum [15] reported one case of autonomic dysreflexia in a participant with SCI performing a single session of interval training, yet it did not alter his overall tolerance to exercise. In AB individuals with heart disease undergoing supervised cardiac rehabilitation, Rognmo et al. [40] reported no deaths and two nonfatal cases of cardiac arrest in response to more than 20,000 hours of interval training, which would suggest that it is relatively safe in persons with low fitness and impaired health. The timing of exercise intervention post-injury remains the most challenging issue, but this is no different than for any other form of upper body exercise and should be based on clinical judgment.

Areas of future study and conclusions

Although there is a large and expanding body of evidence supporting various benefits of HIIT and SIT in able-bodied populations, only limited data exist in persons with SCI. Until substantially more work is performed testing the efficacy and acceptability of interval training in persons with SCI, it seems premature to universally recommend its implementation in this population despite promising data obtained in a few studies. Greater attention is also merited to study the effects of interval training in persons with SCI who are ambulatory, as their greater exercise tolerance may modify resultant adaptations to HIIT. Despite this, existing data show that it is equally effective as MICT in enhancing cardiorespiratory fitness and peak power output which augment exercise tolerance, both of which will improve ability to perform activities of daily living. Early indications that interval training enhances exercise enjoyment and promotes improvements in some biomarkers of cardiometabolic risk are promising and worthy of further study.

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